Payoffs in Military Systems: The Economic Use of X-Ray Lithography for The Manufacture of GaAs Devices

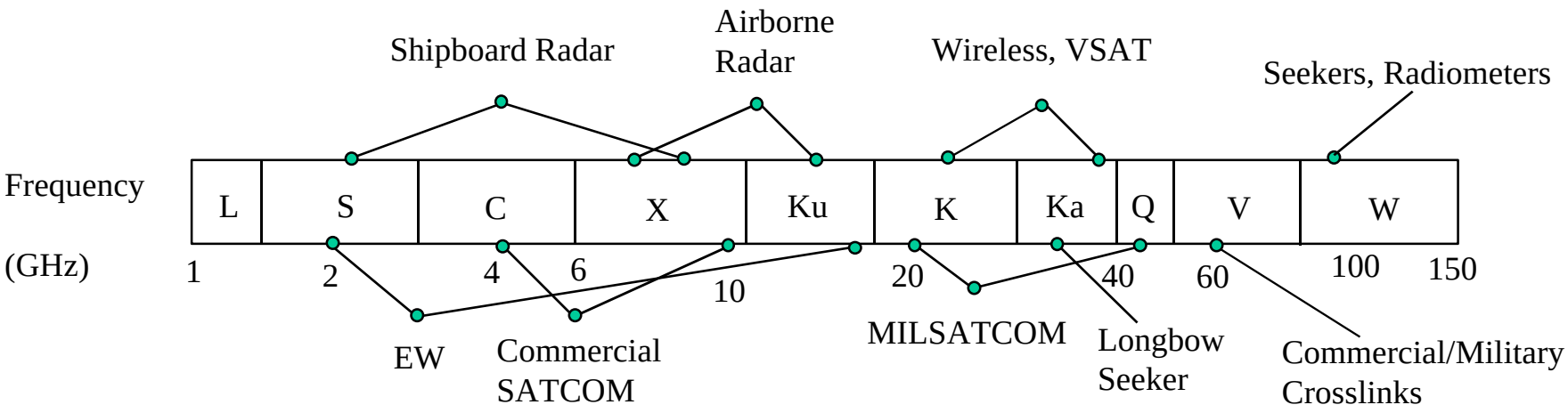
January 2000

Agenda

- **Sanders GaAs Processing and Applications**
- **Lithography key driver for performance and cost**
- **GaAs Lithography requirements**
- **Lithography capitalization costs and lithography cost/wafer**

Military Systems Require Analog GaAs Circuits

- **Circuits are called MMICs**
  - **Monolithic Microwave Integrated Circuits**
- **Used as amplifiers, switches, phase shifters, etc.**
- **Operating frequencies 2-100 GHz**

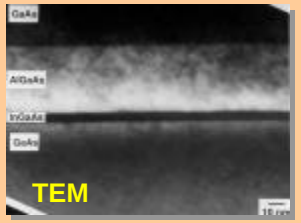


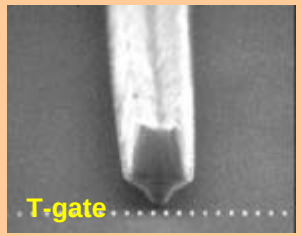
Sanders GaAs MMIC Processing

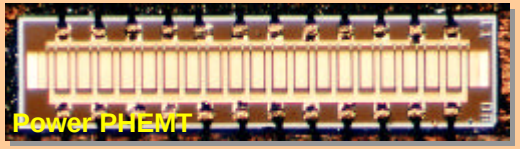
- **Low cost manufacturing of very high performance GaAs MMICs**
  - **Broadband EW and MMW applications**
  - **Demanding performance on power added efficiency (PAE) and noise figure (nf)**
    - **0 40% PAE at 20 GHz, 2.5 db nf at 30 GHz**

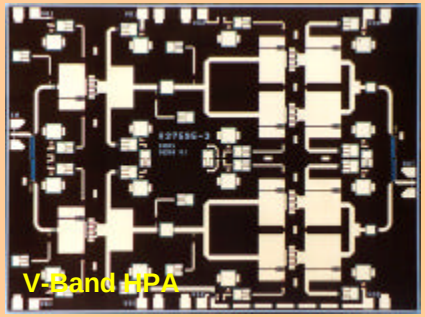
Requires cost effective lithography at 0.15μm

MMIC

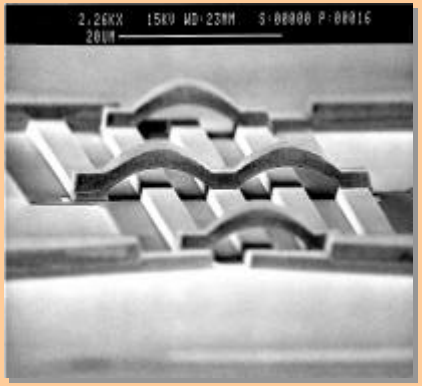


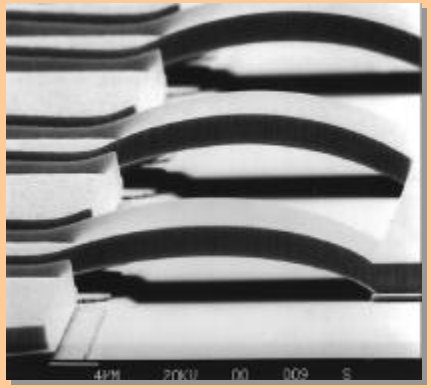




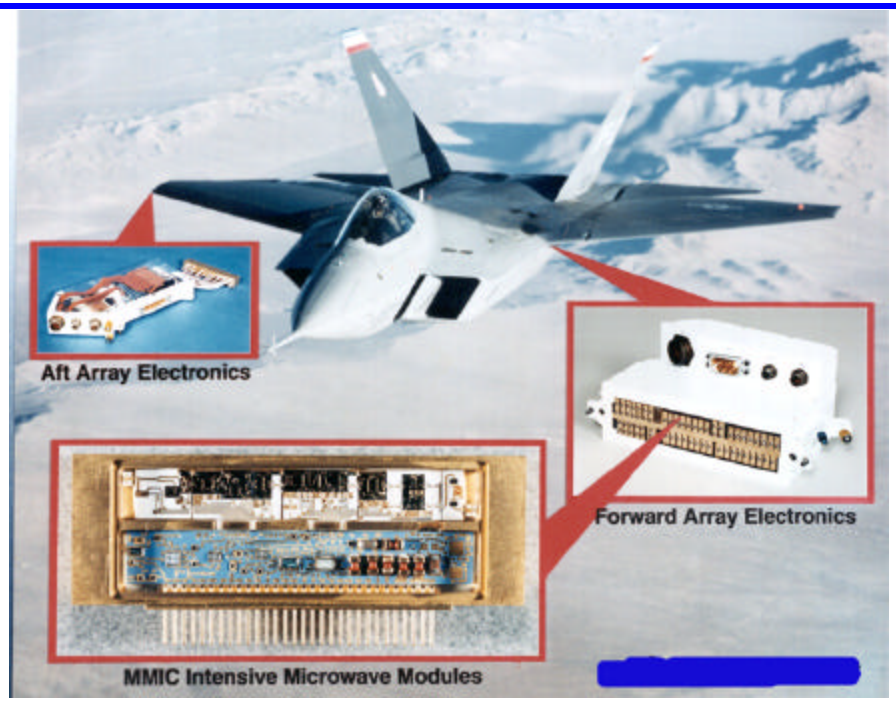


Airbridges

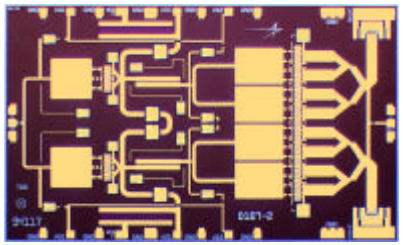




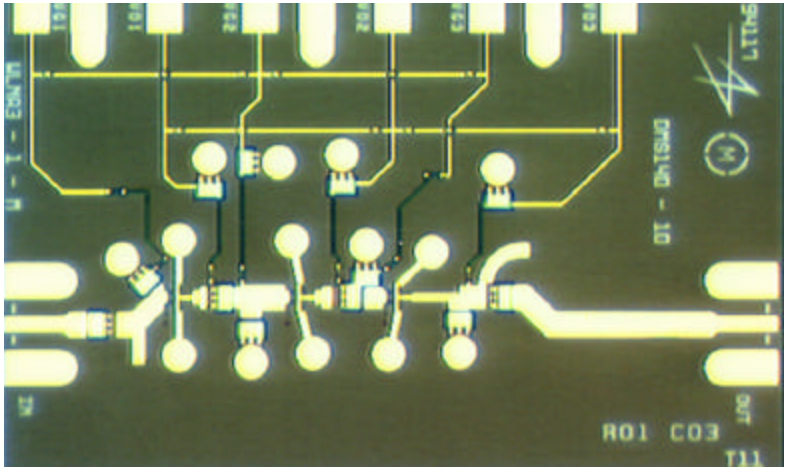
Key Sanders Applications for MMICs



F22 EW Array MMICs

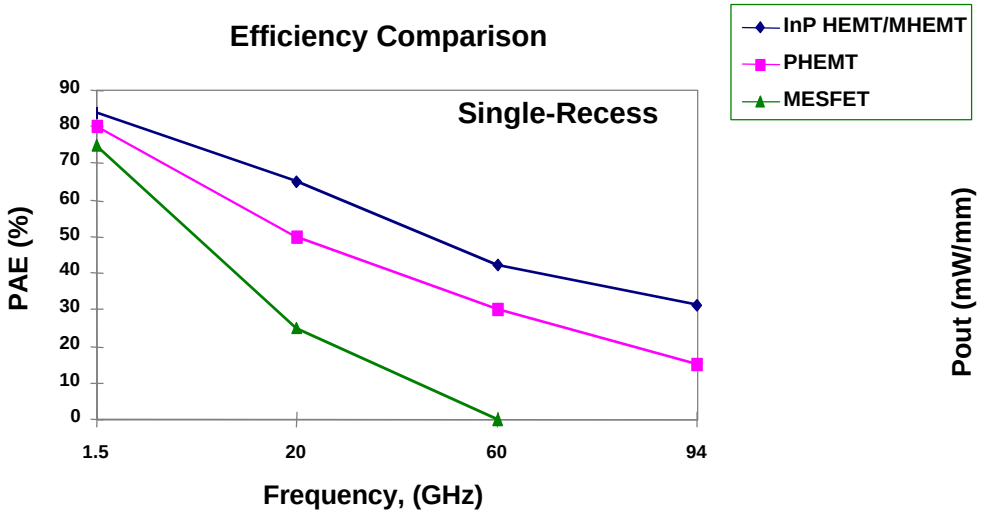


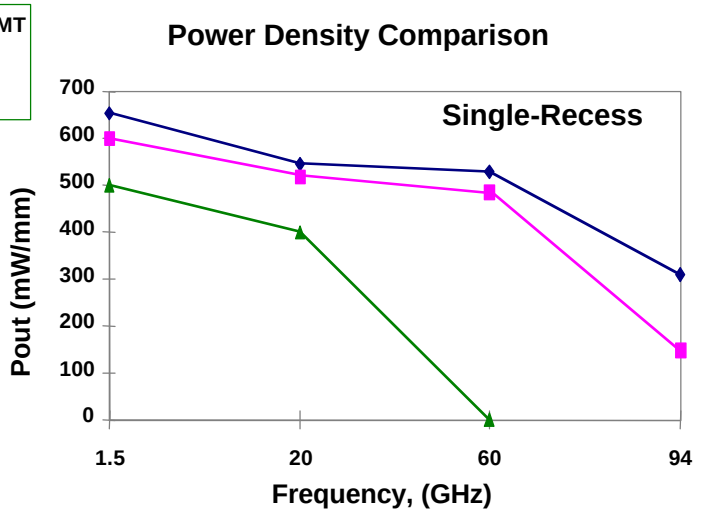
Sanders Longbow HPA MMICs & Module



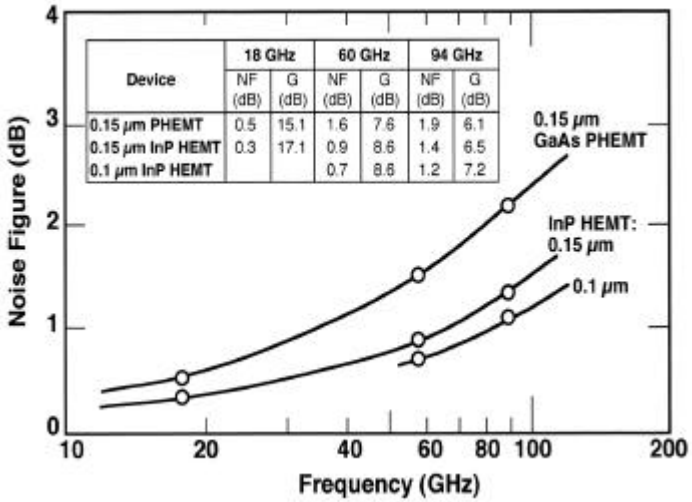
BAT W Band MMIC

Current High Performance MMICs for Manufacturing





InP LN HEMTs & MHEMTs: Lower power consumption, lower NF, higher gain as compared to PHEMTs



InP Power HEMTs & MHEMTs: Superior P.A.E., power density and power gain as compared to PHEMTs

Two Key Drivers for High Performance MMICs

- **Material: Tool development driven by PCS cellular handset market**
  - **Complex epitaxially grown material structures (PHEMT and MHEMT) needed for high performance defense products**
  - **Two vendors provide high throughput MBE (molecular beam epitaxy) tools**

- **Lithography: Smaller gate structures needed for high performance**
  - **0.15μ baseline manufacturing process**
  - **0.25μ for earlier generation programs**

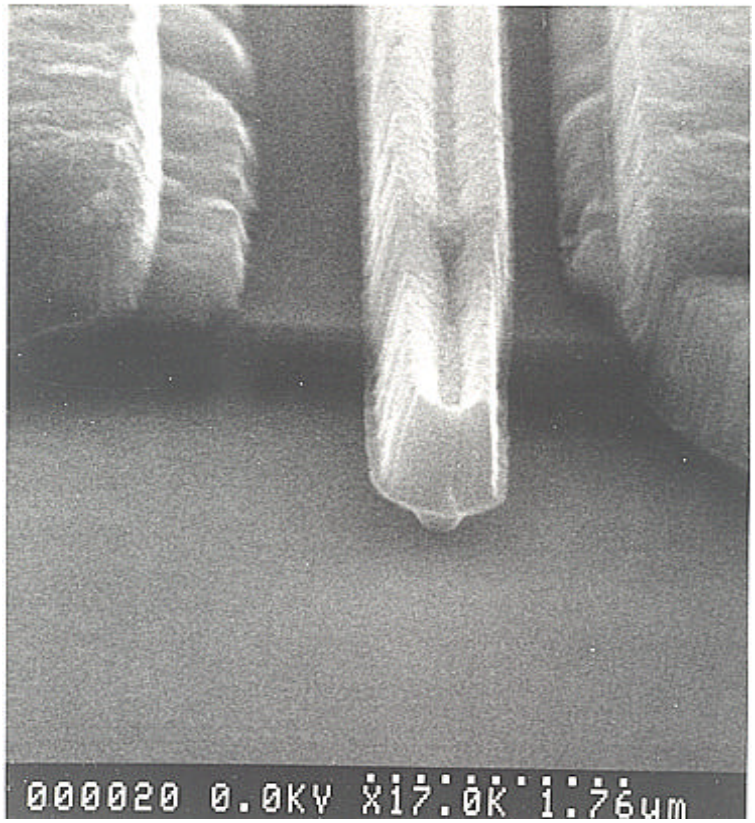
Lithography needs for military applications are driven ahead of commercial markets

Lithography Options for .15μm MMICs

- **E-beams**
  - **Established solution derived from earlier '80s technology (VHSIC and commercial SEM)**
  - **Writing every transistor gate instead of painting entire reticle area with one exposure**
- **X-Ray Lithography**
  - **Stepper based systems give fine resolution (.15μm)**
  - **Demonstrated for 11 years using synchrotron as X-ray source**
  - **Requires new technology for compact X-Ray generation**
  - **Low cost compact X-ray source minimizes investment for military applications which have lower throughput requirements than commercial applications**

DARPA has funded development of new system for initial use on F-22 and Longbow

MMIC Lithography Depth of Field Requirement

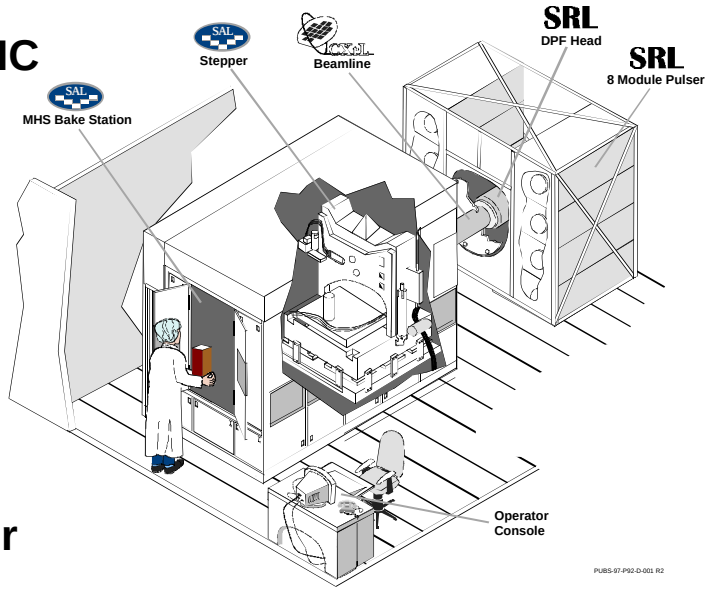


- **Depth of Field Required: >1.5µm**
  - **0.28µm for mesa step**
  - **0.35µm for resist nonuniformity over source-drain metal**
  - **1.0µm for wafer warpage over 30 x 30 mm field**
- **DUV Optical Stepper Depth of Field**
  - **0.5µm at 0.25µm resolution**
  - **as small as 0.2µm at 0.15µm resolution (30 x 30 mm field sizes)**

DUV Optical Stepper will not do MMIC job

Point Source X-Ray Lithography System

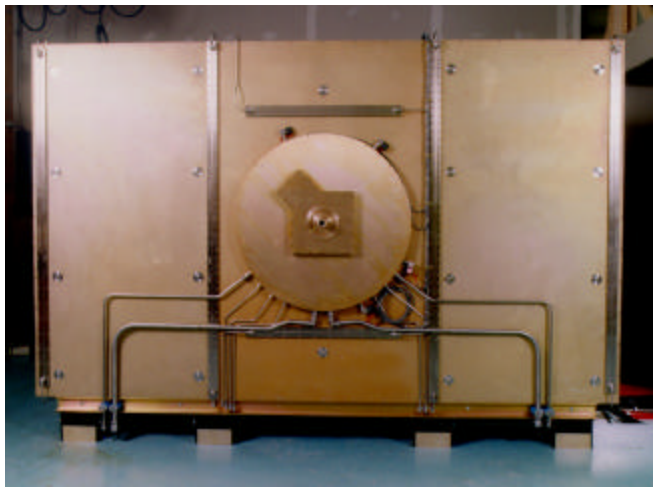
- **Best Next Generation Lithography solution for MMIC industry**
- **System cost and throughput demonstrated**
  - **Throughput of 10,000 6” wafers/yr (2 shift)**
  - **< $10M cost per system**
- **Currently supports 0.15μ and easily scaleable to 0.08μ**
- **Integrated Point Source X-Ray Lithography Stepper Summary**
  - **Funded under DARPA program for implementation on F-22 and Longbow**
  - **Next generation SAL stepper with Dense Plasma Focus source (1kW class X-Ray power) from Science Research Laboratory (SRL)**
  - **Integrated point source stepper system delivered to Sanders, installation complete, first exposure made**



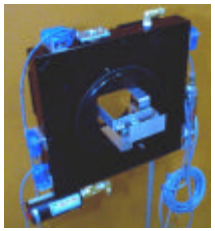
Point Source Stepper System Installed at Sanders, October ‘99

System Configuration

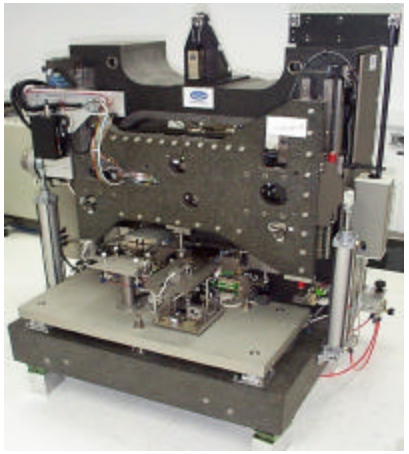
System Components



SRL Point Source

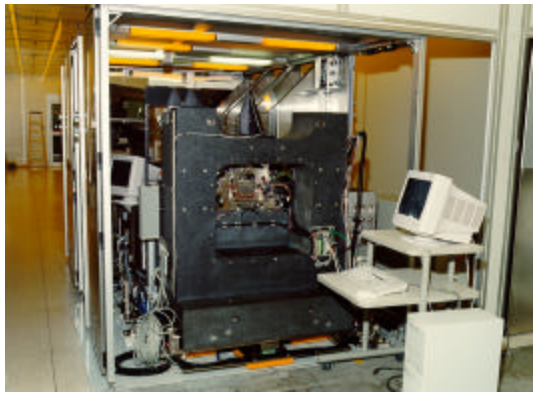


U. Wisconsin Beamline



SAL Stepper

SAL Environmental Chamber



Stepper in Environmental Chamber

Collimator Option

Economic Analysis Approach

- **Consider both lithography capitalization costs and lithography cost/wafer for X-Ray and E-Beam lithography**
- **Baseline case**
  - **10,000 wafers/year**
  - **Multiple shift operation when required**
  - **Included depreciation, operating costs, and loaded labor in operating costs**
- **Compared costs for 0.25μ and 0.15μ MMIC production**
  - **X-Ray throughput same for 0.15μ and 0.25μ**
  - **E-Beam throughput for 0.15μ is 50% of 0.25μ throughput**

X-Ray and E-Beam Lithography Cost Summary

	Capitalization* (% of Total)	Lithography Cost/wafer
X-Ray (0.15μ and 0.25μ)	16%	$271 → $146
E-Beam 0.25μ	34%	$575
E-Beam 0.15μ	51%	$1133

*Based on Sanders 6” upgrade

X-Ray Lithography is Economic Enabler for 6” MMIC Production